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Abstract

PhD graduates hold the highest education degree, are trained to conduct research and can be considered a key element in the creation, commercialization and diffusion of innovations. The impact of PhDs on innovation and economic development takes place through several channels such as the accumulation of scientific capital stock, the enhancement of technology transfers and the promotion of cooperation relationships in innovation processes. Although the placement of PhDs in industry provides a very important mechanism for transmitting knowledge from universities to firms, information about the characteristics of the firms that employ PhDs is very scarce.

The goal of this paper is to improve understanding of the determinants of the demand for PhDs in the private sector. Three main potential determinants of the demand for PhDs are considered: cooperation between firms and universities, R&D activities of firms and several characteristics of firms, size, sector, productivity and age. The results from the econometric analysis show that cooperation between firms and universities encourages firms to recruit PhDs and point to the existence of accumulative effects in the hiring of PhD graduates.

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1. INTRODUCTION

Human capital is one of the main drivers of economic growth (Lucas, 1988). In its composition, PhD graduates are particularly important because they hold the highest education degree and are trained to conduct research (OECD, 2007). Consequently, they can be considered a key element in the creation, commercialization and diffusion of innovations and a main input in knowledge production. The literature shows that the impact of PhDs on innovation and on economic development takes place through several channels such as the accumulation of scientific capital stock (Enders, 2002; Mangematin and Robin, 2003), the enhancement of technology transfers (Faulkner and Senker, 1995; Mangematin, 2000; Lam, 2001) and the promotion of cooperation relationships in innovation processes (Beltramo et al, 2001; Mangematin and Robin 2003; Cruz-Castro and Sanz-Menéndez, 2005). Furthermore, the placement of PhDs in industry provides a very important mechanism for transmitting tacit knowledge from universities to firms.

While there is little doubt about the beneficial effects stemming from PhD's activities, we have a very imperfect knowledge of the labour market for PhD holders and, in particular, on the employment of PhDs by the private sector. This lack of information is worrying because it is the labour market that channels PhDs to the posts where value added is created. Although the role that industry plays in the employment of PhDs is important and is currently increasing, knowledge about the characteristics of the employing firms is very scarce (Stephan et al., 2004). The goal of this paper is to improve our understanding of the determinants of demand for PhDs in the private sector.

The rise of a more knowledge-based economy has led to the emergence of labour opportunities in the private sector. In addition, universities, which have traditionally been the main labour market for PhD holders, are not able to absorb the increasing amount of PhDs (Beltramo et al, 2001; Cruz-Castro and Sanz-Menéndez, 2005). In Spain, 16% of PhD holders are working in the private sector (INE, 2008). Although this percentage has increased in recent years it is below that of the most advanced countries. Nevertheless, in comparison with the United States, Spain as well as other European countries continues to find it difficult to improve the placement of PhDs in industry,

which seems paradoxical (Beltramo et al., 2001). Spain, like other countries, has implemented programs aimed at improving the low innovative capacities of firms through the incorporation of highly qualified human capital (Cruz-Castro and Sanz-Menéndez, 2005). To have better knowledge of the characteristics of the firms that demand PhDs is particularly important in defining policy initiatives to improve the quality of human capital in firms.

Some of the factors that have been pointed to as potential determinants of the demand for PhD holders in the private sector are the following: cooperation between companies and universities, the subcontracting of R&D to universities, the amount of R&D expenditure of firms, the stock of scientific capital and the existence of R&D departments (Mangematin, 2000; Beltramo et al, 2001; Slaughter et al, 2002; Cruz-Castro and Sanz-Menéndez, 2005; Wallgren and Dahlgren, 2005). Taking the functions that PhDs may carry out in firms into account together with some previous empirical findings, three main potential determinants of the demand for PhDs are considered: cooperation between firms and universities, the R&D activities of the firm and several characteristics of firms such as, size, economic sector, productivity and age.

To examine the determinants of the demand for PhDs in the private sector, we base our empirical analysis on an innovation survey which includes information about 241 firms located in Valencia, a Spanish region with medium-low technological content. In regions with low technological content and weak absorptive capacity to improve the incorporation of human capital may have significant effects because having employees with a graduate degree affects the propensity to innovate (Lundvall and Lorenz, 2008). The analysis is carried out in two phases. In a first stage we use a logit model to explore which firm characteristics are relevant to explaining PhD recruitment. In a second stage, we use a multinomial logit to assess whether firms' propensity to recruit R&D staff depends on the nature of the institution (university, technology centre or in the company itself) where the researcher completed his or her thesis.

The rest of the paper is organised as follows. After this introduction, in the next section the main variables that can affect the employment of PhDs by firms are presented according to the most consistent conclusions of the available studies. In the third section, after explaining the database and some descriptive statistics, an applied analysis

is carried out and the results are presented. The paper ends with a section for conclusions that includes some recommendations for the design of innovation policies.

2. DETERMINANTS OF THE DEMAND FOR PhDs

The labour market for PhDs is experiencing substantial changes with an increasing number of doctorate holders working in the private sector. PhDs can carry out different activities in firms but to conduct research is one of the most important ways of taking advantage of this human capital. Although there is no specific theoretical framework to select the factors that influence the demand of firms for PhDs for R&D activities, this demand is related to the strategy and organisation of R&D activities in firms and to the role that PhDs may play. As has been mentioned above, the literature has pointed out that some possible determinants are cooperation between companies and universities, the subcontracting of R&D to universities, the amount of R&D expenditure of firms, the stock of scientific capital and the existence of R&D departments.

PhDs compete in the labour market with other qualified personnel and demand for them by firms is related to the functions that they may carry out and with their specific qualifications. Three aspects seem particularly important in analysing the characteristics of the firms that influence the demand for PhDs. Firstly, PhDs have been trained to conduct research and compared with other graduates they are used to working on problems with an unknown solution. This means that they are able to carry out more sophisticated and complex R&D activities, these being very important inputs for firms that use a science, technology and innovation (STI) mode of innovation, mainly based on the production and use of scientific and technical knowledge (Jensen et al., 2007). PhDs are therefore a way to improve the stock of scientific capital in firms (Vinding, 2004) and have positive effects on knowledge production and on creating favourable environments for research (Enders, 2002; Slaughter et al., 2002; Mangematin and Robin, 2003). Nevertheless, demand for them, particularly in the case of small and medium firms, is frequently limited by a lack of information about the activities that PhDs may carry out and by the view that the training of PhDs is mainly theoretical and of little use in meeting the technological needs of the firms.

Secondly, having PhDs on the staff allows firms to access scientific knowledge (Navarro, 2009), to participate in external networks with the scientific community and when a firm needs to solve a technical problem makes it easier to gather information from academic contacts (Hicks, 1995). Particularly, PhD holders are highly important in university-firm relationships because they are significant producers of knowledge in collaborative research projects, are an important channel for technology transfer and they favor network configurations between firms and universities (Thune, 2009b).

Therefore, cooperation between firms and universities is considered to be one of the main variables determining the recruitment of PhD holders. Nevertheless, some analyses point out that the tendency to use R&D agreements instead of developing internal research may have a negative impact on the recruitment of PhD graduates. The substitution of internal research by external relationships may lead to a reduction of the demand for PhDs due to the limited number of people needed to maintain technological updating by seeking research alliances (Beltramo et al., 2001).

Thirdly, employees with high-level qualifications allow the absorptive capacities of the firms to be improved. This concept was initially introduced by Cohen and Levinthal (1989), who state that the absorptive capacity of a firm depends on its previous experience in innovation and on its current abilities, their capacity to value, assimilate and use knowledge from external sources being particularly important.

Among the factors that condition the absorptive capacities of firms the availability of human resources is a key variable because they determine the internal knowledge base of the firm and the ability to assimilate and use external knowledge. Absorptive capacity is also a function of the cultural distance between the firm and the supplier of the external knowledge. This heterogeneity or differences in organisational approaches may restrict the interaction that is necessary in the process of the supplying and absorbing complex knowledge. PhDs have the training required to evaluate external knowledge, especially scientific knowledge, and also have cultural proximity to suppliers of external knowledge, particularly when the source is a university or a technology centre that provides intensive research services. Furthermore, the knowledge and abilities possessed by PhDs allows them to be able to combine internal capacity with external collaboration and so improve the innovative performance of firms.

Departing from these considerations, we examine three groups of variables used to capture the main factors that explain the demand for PhDs, giving particular attention to the effects that relationships with universities have on the recruitment of PhDs by industry. These three groups of variables are the degree of cooperation between firms and universities; R&D activities and their organization in the firm and some specific characteristics of firms.

Firstly, we approach the cooperation between firms and universities through two variables, the share of R&D subcontracted to universities and willingness to recruit university researchers temporarily. Both variables capture the access of the firms to knowledge generated in universities and also their interest in and proximity to academic research.

The R&D organization and the activities of firms are approached with five variables: the effort in R&D, the existence of an R&D department, expenditure on R&D in the development of new products, the prior hiring of PhDs and the subcontracting of R&D activities. For the first four variables the expected sign is positive. Firstly, firms those make a greater effort in R&D, have an R&D department and devote a high proportion of their research to developing new products are expected to use more PhDs. These firms are used to carrying out systematic R&D and are more interested in scientific knowledge. Therefore, the recruitment of PhDs is a way of improving their absorptive capacity and their technological and scientific stock of capital (Stephan et al., 2004; Wallgren and Dahlgren, 2005). Secondly, to have PhDs reduces some information barriers that firms may confront in their decisions to employ PhDs. Finally, firms that use external sources and subcontract R&D activities may need PhDs to develop these relationships and to absorb the resulting knowledge properly. Nevertheless, as specified above, if this means a substitution process, reducing internal R&D may lead to a decrease in the recruitment of PhDs.

Finally, the specific characteristics of firms considered to explain the demand for PhDs are the size of the firm, its age, its productivity and the industrial sector to which they belong. High-tech firms are characterized by the systematic development of R&D activities and have a greater propensity to employ resources with a high technological

level, including highly skilled workers. For this reason, high-tech firms are more likely to hire PhDs to conduct their R&D activities (Heyer, 1985; Grimpe and Sofka, 2009).

In the case of the size and the age of the firm the effect of these variables is ambiguous. Larger firms with R&D departments and greater absorptive capacity may be more interested in hiring PhDs. Nevertheless, the greater flexibility of smaller firms in terms of simpler and less bureaucratic organizational structures facilitates their ability to deal better with changes (Liao et al., 2003) and to be more disposed towards hiring PhDs. Furthermore, the activity of the firm seems more important than its size in explaining the demand for PhDs, as is shown for instance by the role that small firms play in biotechnology (Stephan et al., 2004).

In relation to the firm's age, Mowery et al. (1996), Sorensen and Stuart (2000) and Rao and Drazin (2002) conclude that reinforcement of the absorptive capacity of firms is related to knowledge fund accumulation, which is more likely in those firms that have been in operation for a longer time. Therefore, the probability that a firm will hire a PhD would increase the older it is. However, older firms tend to have more routinized innovation processes and they are less able to adapt themselves to any new procedures of innovation. On the other hand, newer firms have more flexible innovation systems (Tushman and Romanelli, 1985) and tend to present a higher probability of innovation (Huergo and Jaumandreu, 2004) being therefore more likely to employ PhDs.

Table 1

3. DATA AND RESULTS

A survey conducted in 2007 of firms from the Valencian Community has been used to analyse the determinants of the recruitment of PhDs. Valencia is a region characterized by having an industrial structure with a medium-low technological level. The basic characteristics of its industrial structure are firstly a specialization in products of a lasting nature, goods aimed at final consumption, and export-oriented goods, especially for the European Union, and secondly a high proportion of small and medium-sized industries, which accentuates dependency on exterior resources to feed and support innovation processes (Mas-Verdú, 2007). From a more specific point of view, the

Valencian Community has been characterized as a region with low absorptive capacity (Azagra *et al.*, 2006 and 2009). The main features of the region are: the low-tech profile of its economic structure, the weaknesses of its innovation activities and the scarcity of qualified personnel in firms, even in knowledge-intensive sectors. Nevertheless, as Azagra (2007) and Azagra *et al.* (2009) have stressed this context is compatible with the existence of important university – industry links and universities to an extent have adapted themselves to this low level of regional absorptive capacity.

The survey used in this paper has a similar structure and content as that of the Community Innovation Survey but includes some complementary questions on human resources, external R&D resources and policy instruments. The whole survey population is composed of 988 firms that carried out research activities, technological development and innovation during the period 2004-2006. Out of the total number of firms we have information for 280. In addition, due to some inconsistencies found in some responses, 39 firms have also been deleted. This leaves a sample of 241 firms. The information in the survey was obtained through direct interviews with the managers. The interviews covered topics such as the performance of innovation activities, the use of services and the availability of R&D support programs offered by public administrations.

The survey provides information on managers' preferences about the educational level of their future employees. In order to establish the demand for PhDs we have created a dummy variable that takes the value of one when the manager prefers that the future R&D employee has a doctorate degree, and zero otherwise. Moreover, and in order to add robustness to the empirical analysis, we have used managers' assessment of hiring PhDs; in this case the dummy variable is equal to one when the managers' evaluation of the recruitment of PhDs is "valuable" or "very valuable" and zero in any other case.

Complementarily, the information from the survey allows the analysis of the differences in the characteristics of the firms that prefer graduates that have completed their theses in a university or in a technology centre and those that prefer graduates who are not PhDs but can develop their theses in a R&D project in the firm. These distinctions are important from a policy point of view, particularly taking into account the existence of

programs in some European Union countries aimed at encouraging graduates to complete their doctoral theses in firms (Thune, 2009a).

The descriptive analysis shows that 61% of the firms consider PhDs valuable or very valuable, but only 10.4% prefer to hire a PhD holder and only 15.4% have a PhD employed on the staff. For the specific group of firms that consider PhDs valuable or very valuable, the percentage of firms that would actually choose a PhD to conduct the R&D activities is 17%. This shows that there is a large group of firms that recognize the importance of PhDs in innovation activities, but that prefer to hire employees with a lower educational qualification to carry out these activities. This limitation to the PhD recruitment process in the private sector seems to be common in different countries across Europe, where the mismatch between demand and supply of PhDs has led to the implementation of specific programs intended to incorporate PhDs into the labor market and to facilitate the mobility of researchers towards the private sector, such as the “dk21 plan”(Denmark), the “PROINOV” (Portugal), the “Techstart” and “Techman” (Ireland), the “CIFRE program” (France) or the “Torres-Quevedo” in Spain (European Commission, 2001).

The average size of the firms analysed is 130 workers and the average turnover is 26.3 million Euros. These firms have an average age of 20 years and more than half of them belong to medium and high-tech technology sectors. The average R&D effort is 9%, 64% of the firms have an R&D department and 15% of the firms employs at least one PhD. As to cooperation within firms and universities we find that average subcontracting of R&D activities to universities is 12%. Interestingly, 46% of firms show a positive attitude towards the temporary hiring of university researchers (table 2).

Table 2

The characteristics of the firms vary substantially with their preferences for differently educated employees (see table 3). Firms that most appreciate the degree of education of their future employees tend to maintain solid cooperation links with universities: 76% of the firms that prefer their new recruits to be PhDs are interested in temporarily recruiting university researchers and subcontract 28% of their R&D external

expenditures to universities. Finally, firms willing to hire PhDs also make a greater effort in R&D than firms reluctant to hire PhDs.

Table 3

Firms that prefer to recruit PhD holders have similar characteristics to firms that have already incorporated a PhD into their staff, showing that there is a high degree of correspondence between managers' assessments and the real characteristics of the firms. These similarities are greater in R&D activities, especially in variables like the R&D effort, the outsourced R&D activities and the existence of an R&D department. In the empirical analysis, it is better to use the managers' preferences for hiring PhDs to examine the demand for PhD holders rather than the firms that already have one. This approach avoids endogeneity problems and truly approximates the firm's behavior regarding the demand for PhDs.

The analysis of the characteristics of firms that favour PhD recruits is carried out in two steps. In the first one we analyse, using a logit model, the determinants of the demand for PhD employees using managers' preferences on the recruitment of PhDs as the endogenous variable ("preferences for PhDs"). Moreover, we estimate the same model using managers' assessment of hiring PhDs as the endogenous variable ("assessment of hiring PhDs") to add robustness to our results and to examine whether there are differences between these alternatives. In order to reinforce the results we also estimate the determinants of the demand for PhDs only for firms belonging to sectors of medium-high and high technology content, since this group of firms performs R&D activities more systematically, and therefore has a greater interest in highly qualified personnel.

In the second step, we study the preference of firms interested in hiring PhDs for the different institutions where a thesis can be done. In this case, given that the endogenous variable takes three different values (universities and public research centres, technology centres or no PhD), we implement a multinomial logit for unordered categories where the base category is having studied the PhD in a university or in a public research centre.

The results (table 4) show that university-firm interaction plays an important role in explaining the demand for PhDs. This result suggests that an increase in the subcontracting of R&D to universities and in the mobility of university researchers to the private sector would have a positive effect on the demand for PhDs. The effect of the university-firm interaction on the demand for PhDs is larger for medium-high and high technology firms, showing that firms in these sectors that cooperate with universities are more likely to hire a PhD than high-tech firms with no interaction with universities or than low-tech firms.

Previous PhD recruits also favour the likelihood of both positively assessing employees' qualifications and hiring more PhDs. This result strengthens the hypothesis of Beltramo et al. (2001) that existing levels of scientific stock encourage future highly qualified recruits. This suggests that there is a cumulative effect in a way that once a certain number of PhDs have been reached, it is more likely a firm will recruit new PhDs.

Additionally, firms performing R&D more intensively, through a higher R&D effort, or devoting more resources to developing new products, or firms that have an R&D department, show a higher propensity for hiring PhDs. However, this effect does not hold when the endogenous variable is the assessment of hiring PhDs, showing that although a high proportion of the firms state that hiring PhDs is valuable, only firms that use R&D more intensively have clear intentions to recruit them.

As to the set intrinsic characteristics of firms, those belonging to medium-high and high technology sectors are more likely to prefer the recruitment of PhDs, while there is not enough evidence of significant relationships between the demand for PhDs and the age, productivity and size of the firm. On the other hand, productivity positively affects managers' assessment of hiring PhDs. Moreover, the results show that there is a U-shape relationship between the firm size and managers' assessment of hiring PhDs which means that the probability of having a positive assessment of the recruitment of PhDs decreases as the firm size increases, and from a certain size, this probability increases with greater firm size.

Table 4

Finally, the results show that there are some differences in the characteristics of the firms that prefer PhDs from different institutions. Firms that have a positive attitude towards the temporary recruitment of university researchers and firms that belong to medium-high and high-technology sectors prefer to hire PhDs that have done their theses within a university rather than in a technology centre. On the other hand, firms that outsource R&D are more likely to hire PhDs coming from technology centres or to recruit highly qualified workers that want to carry out their theses on projects related to the firm's activity.

Table 5

4. CONCLUSIONS

Human capital is a key input in knowledge production and in the innovation capacity of firms. The availability of qualified personnel allows firms to develop innovations and to absorb existing knowledge. Particularly, doctoral graduates are very important in the creation, commercialisation and diffusion of innovations. In addition, the principal source of academic knowledge transfers supporting business innovation remains the flow of university-trained graduates (Dasgupta and David, 1994; David and Metcalfe, 2007). Although industry plays an important role in the employment of PhDs, very little is known about the characteristics of the firms that employ them (Stephan et al., 2004). The objective of this paper is to go further in this field of research and add new evidence on the determinants of the demand for PhDs in the private sector. The analysis is based on Valencia, a Spanish region of medium-low technological content, where improving the innovative capacities of firms is a key element in fostering regional economic development.

The paper is focused on the characteristics of firms that explain the demand for PhDs. Three main potential determinants of the demand for PhDs have been considered. These are the degree of cooperation between firms and universities, the involvement of firms in R&D activities and some specific characteristics of firms, size, age, sector and productivity. The results from the econometric analysis show that firms that cooperate with universities and carry out R&D activities (have an R&D department, incur significant R&D expenditure or have at least one PhD on their staff) are more likely to

value the level of training of their future employees highly and prefer them to hold a PhD degree. There is also evidence that firms that devote more resources to product innovations than to process innovations prefer to recruit PhDs. In relation to the characteristics of firms we find that belonging to a high technology sector matters while the other variables are not significant. Finally, we also find that the nature of the institution where the thesis has been made matters: high and medium technology companies that cooperate with universities prefer PhDs coming from a university. On the other hand companies that subcontract R&D activities to firms prefer PhDs with experience in the private sector.

The analysis is not without limitations. Firstly, although the database provides comprehensive information on the characteristics of firms and on the assessment of managers of human resources and specifically on how they value PhDs, there is no information on the characteristics of the PhDs employed by firms or, in general, on PhDs. It might have been convenient to know more about the characteristics of doctorate holders that are interested in working in industry to analyse the existence of possible mismatches. Secondly, the database provides information on the participation of firms in public programmes to support R&D activities. Nevertheless, there is no information on participation in the specific programmes designed to facilitate the incorporation of highly qualified human capital, such as PhDs, into firms. Therefore we have neither been able to control for this variable nor to know the impact of these instruments on the recruitment of PhDs.

The results have some implications for the design of innovation policy. Firstly, cooperation between firms and universities encourages firms to recruit PhDs to develop these relationships. Cooperation also possibly smoothes out the entry of researchers into the firms and reduces some information asymmetries inherent in the hiring of PhDs. Therefore establishing links between firms and universities and fostering labour mobility mechanisms might lead to an increase in the number of PhD recruits in the private sector. Secondly, the fact that the presence of at least one PhD in the firm encourages the recruitment of additional PhDs suggests the existence of cumulative effects in the hiring of PhD graduates. Thirdly, the finding that the existence of R&D departments positively affects the recruitment of PhD graduates indicates that firms need proper infrastructures to be able to absorb PhDs. Finally, the results point towards

the advantages of developing joint action to improve innovation in firms. It is convenient that these actions adopt an integrated approach to encouraging some factors that can favour innovation, such as investment in R&D departments, cooperation with universities and the mobility of researchers between public and private organisations.

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Table 1. Description of the variables and expected effects

		Expected effects
Cooperation between firms and universities		
<i>Temporary recruitment university researchers</i>	Dummy variable equal to one when the firm is in favor of the recruitment of university researchers	+
<i>Subcontracting of R&D to universities</i>	Percentage of R&D subcontracted to universities	+
R&D activities		
<i>R&D effort</i>	R&D expenditures in terms of the total sales	+
<i>PhDs</i>	Dummy variable equal to one when the firm has at least one PhD working in its staff	+
<i>% R&D expenditure on new products</i>	Percentage of R&D used to improve or create new products	+
<i>R&D department</i>	Dummy variable equal to one when the firm has an R&D department	+
<i>Subcontracting of R&D</i>	Dummy variable equal to one when the firm outsources R&D activities to other firms or institutions	+
Characteristics of firms		
<i>Size</i>	Number of employees	?
<i>Productivity</i>	Sales per worker	+
<i>Age</i>	Age of the firm	?
<i>Medium and high-tech sectors</i>	Dummy variable equal to one when the firm belongs to a medium or high technology sector	+

Table 2. Descriptive statistics

	Obs	Mean	Desv. Est	Min	Max
Endogenous variables					
<i>Preferences for PhD holders</i>	241	0.10	0.31	0.00	1.00
<i>Assessment of hiring PhDs</i>	241	0.61	0.49	0.00	1.00
Recruitment of highly qualified human resources					
<i>PhD within a Universities</i>	241	0.24	0.43	0.00	1.00
<i>PhD within a Technology center</i>	241	0.36	0.48	0.00	1.00
<i>No thesis</i>	241	0.40	0.49	0.00	1.00
Cooperation between firms and universities					
<i>Temporary recruiting university researchers</i>	241	0.46	0.50	0.00	1.00
<i>Subcontracting of R&D to universities</i>	241	12.61	28.46	0.00	100.00
R&D activities					
<i>R&D effort</i>	241	0.09	0.17	0.00	0.88
<i>PhDs</i>	241	0.15	0.36	0.00	1.00
<i>% R&D expenditures in new products</i>	241	0.20	0.30	0.00	1.00
<i>R&D department</i>	234	0.63	0.48	0.00	1.00
<i>Subcontracting of R&D</i>	240	0.64	0.48	0.00	1.00
Firm characteristics					
<i>Size</i>	241	130.36	513.64	1.00	7608.00
<i>Productivity (thousands)</i>	237	168.23	89.59	72.57	517.09
<i>Age</i>	241	20.29	16.21	1.00	117.00
<i>Medium-high and high-tech</i>	241	0.52	0.50	0.00	1.00

Table 3. Preferences of firms for differently educated employees

	Assessment of hiring PhDs		Preferences for PhD holders		PhDs in the workforce	
	High	Low	Yes	No	Yes	No
<i>Cooperation between firms and universities</i>						
<i>Temporary recruitment university researchers</i>	0.57	0.30	0.76	0.43	0.49	0.46
<i>Subcontracting of R&D to universities</i>	16.25	6.91	28.24	10.80	18.95	11.46
<i>R&D activities</i>						
<i>R&D effort</i>	0.10	0.08	0.28	0.07	0.23	0.07
<i>PhDs</i>						
<i>% R&D expenditure on new products</i>	0.19	0.22	0.16	0.21	0.16	0.21
<i>R&D department</i>	0.62	0.65	0.68	0.63	0.70	0.62
<i>Subcontracting of R&D</i>	0.67	0.59	0.76	0.62	0.70	0.63
<i>Characteristics of firms</i>						
<i>Size</i>	141.23	113.36	76.92	136.55	137.68	129.03
<i>Productivity (thousands)</i>	170.14	166.95	168.85	165.86	172.21	167.68
<i>Age</i>	18.88	22.48	15.36	20.86	17.38	20.81
<i>Medium-high and high-tech sectors</i>	0.61	0.38	0.80	0.49	0.78	0.47

Table 4. Demand for PhD holders

	Preferences for PhDs		Assessment of hiring PhDs	
	(1)	(2)	(1)	(2)
<i>Cooperation between firms and universities</i>				
<i>Temporary recruitment university researchers</i>	2.32 (2.81)***	1.86 (2.49)**	0.98 (2.73)***	1.35 (2.33)***
<i>Subcontracting of R&D to universities</i>	0.01 (1.67)*	0.02 (1.78)*	0.02 (2.43)**	0.04 (2.44)**
<i>R&D activities</i>				
<i>R&D effort</i>	3.65 (2.06)**	4.26 (2.48)**	-0.61 (-0.65)	-1.38 (-1.08)
<i>PhDs</i>	3.21 (4.15)***	2.64 (3.53)**	1.76 (3.12)***	2.77 (2.99)***
<i>% R&D expenditure on new products</i>	0.73 (3.18)***	0.05 (1.46)	0.30 (1.30)	-0.74 (-0.98)
<i>R&D department</i>	1.33 (1.68)*	0.97 (1.33)	-0.07 (-0.19)	-0.41 (-0.61)
<i>Subcontracting of R&D</i>	0.42 (0.44)	0.47 (0.50)	-0.14 (-0.40)	-1.32 (-2.21)**
<i>Characteristics of firms</i>				
<i>Size</i>	0.01 (0.75)	0.01 (0.76)	-0.01 (-1.80)**	-0.01 (-0.10)
<i>Size²</i>	-2.45·10 ⁻⁰⁵ (-0.96)	-1.65·10 ⁻⁰⁵ (-0.94)	3.67·10 ⁻⁰⁶ (1.65)*	-7.01·10 ⁻⁰⁷ (-0.04)
<i>Productivity</i>	-1.53·10 ⁻⁰⁶ (-0.93)	-9.73·10 ⁻⁰⁸ (-0.07)	1.29·10 ⁻⁰⁶ (1.96)**	2.49·10 ⁻⁰⁶ (-0.78)
<i>Age</i>	0.01 (0.13)	0.01 (0.17)	-2.78·10 ⁻⁰³ (-0.22)	-0.01 (-0.87)
<i>Medium-high and high-tech sectors</i>	1.60 (1.83)*	-. -	0.96 (2.75)***	-. -
<i>Constant</i>	-8.23 (-5.37)***	-6.26 (-4.65)***	-0.61 (-1.16)	1.04 (1.13)
<i>Num obs</i>	193	103	193	103
<i>Pseudo R²</i>	0.506	0.429	0.197	0.251

Note: In columns (1) the sample is composed of all the firms while in columns (2) only firms in medium-high and high-technology sectors are included.

Z-values in brackets. *, **, *** indicates significance at 90%, 95% and 99% respectively

Table 5. Recruitment of highly qualified human resources

	Thesis in technology center	No thesis
<i>Cooperation between firms and universities</i>		
Temporary recruitment university researchers	-1.20 (-2.86) ^{***}	-1.29 (-3.04) ^{***}
Subcontracting of R&D to universities	-0.01 (-1.31)	0.00 (0.20)
<i>R&D activities</i>		
<i>R&D effort</i>	-1.76 (-1.32)	-0.01 (-0.01)
<i>PhDs</i>	-0.56 (-1.15)	-0.80 (-1.38)
<i>R&D department</i>	-0.06 (-0.15)	0.47 (1.16)
<i>Subcontracting of R&D</i>	0.98 (2.21) ^{**}	0.78 (1.70) [*]
<i>Characteristics of firms</i>		
<i>Size</i>	-0.01 (-1.45)	-0.01 (-1.79) [*]
<i>Size²</i>	0.00 (1.08)	0.00 (1.16)
<i>Productivity</i>	0.00 (0.19)	0.00 (0.03)
<i>Age</i>	0.02 (1.36)	0.03 (1.79) [*]
<i>Medium-high and high-tech sectors</i>	-0.74 (-1.73) [*]	-1.17 (-2.71) ^{***}
<i>Constant</i>	1.25 (2.17) ^{**}	1.16 (2.12) ^{**}
<i>Num obs.</i>		229
<i>Pseudo R²</i>		0.097

Note: Z-values in brackets. ^{*}, ^{**}, ^{***} indicates significance at 90%, 95% and 99% respectively



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